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ADAPTATION OF AN IN SITU GROUND-BASED TROPOSPHERIC OH/HO2 INSTRUMENT FOR AIRCRAFT USE

submitted to

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This technical report describes the first year of the development of an OH/HO_2 instrument for the DC-8 aircraft. We have named this instrument the "Airborne Tropospheric Hydrogen Oxides Sensor", or ATHOS. While some areas of instrument development lag behind our proposed schedule, the overall picture is that we should be able to deliver an instrument for flights in the early part of 1996 if we experience no more unexpected delays.

A brief description of the instrument operation is as follows. The instrument uses laser induced fluorescence to measure OH and HO_2 simultaneously. OH is both excited and detected with the $A^2\Sigma^+$ (v'=0) $\rightarrow$ $X^2\Pi$ (v"=0) transition near 308 nm. The ambient air is slowed from aircraft speed to 20 m s^{-1} in an aerodynamic nacelle, and then pulled into low-pressure detection chambers by a vacuum pump (Stevens, P.S., J.H Mather, and W.H. Brune, Measurement of tropospheric OH and HO_2 by laser-induced fluorescence at low pressure, *J. Geophys. Res.*, *99*, 3543-3557, 1994.) Detection occurs in the detection chambers at the intersections of the airflow, the laser beams passed through multipass White cells, and the detector fields-of-view. The laser has a 5 kHz repetition rate, 35 ns long pulses, and can be tuned on and off resonance with the OH transition to determine OH fluorescence and background signals. The detector is gated to detect the OH fluorescence after each laser pulse has cleared the detection cell. A reference cell containing OH indicates when the laser is on and off resonance with the OH transition. HO_2 is detected by adding NO inside the flow tube leading to the second detection chamber. The reaction of NO with HO_2 produces OH, which is detected by laser induced fluorescence. An in-flight calibration system creates a known amount of OH outside the detection chamber inlet.

The basic configuration of the instrument is shown in Figure 1. Air is slowed from the aircraft speed of about 250 m s^{-1} to 5-40 m s^{-1} by the sampling nacelle. The air is then drawn into the detection cell inlet, and OH and HO_2 are detected simultaneously in two detection axes by the technique described in the previous paragraph. The detection inlet is set perpendicular to the flow so that rain and debris pass by the inlet and do not impact on it. This arrangement will give ATHOS rapid response capability in a wide range of environments, including in clouds.

Most instruments are mounted in the passenger compartment of the DC-8 (Figures 2,3, and 4). ATHOS will go in the forward cargo bay and will use the nadir #2 hatch, so that the sampling nacelle is hanging under the aircraft. The operators will sit in the passenger compartment with a monitor, keyboard, and mouse to control the instrument. Placing the instrument underneath the aircraft has several advantages for measuring a reactive species such as OH. First, because the sampling flow tube must be kept as short as possible to minimize the potential for OH loss, ATHOS must be placed near the front of the DC-8 where the boundary layer is thinner. If it were placed in the main cabin, the 12" diameter nacelle could potentially disturb the flow into the inlets of other instruments. By placing ATHOS underneath the aircraft, we remove the potential interference with other instruments downstream but keep the sampling flow tube as short as possible. Second, because the DC-8 flies slightly nose-up, the boundary layer underneath the aircraft is slightly thinner and better controlled than it is on the sides. Third, because only the operators with a computer monitor and keyboard will be in the main cabin, ATHOS takes up less space in the main cabin, making it compatible with a larger array of instrument configurations. Fourth, if something were to happen to the sampling nacelle and it were to come off, it would not be a danger to the aircraft control surfaces at the rear of the aircraft, as it might be if mounted on the side of the aircraft. A few negative aspects are far outweighed by these positive ones.

Instrument design, development, and construction is proceeding. For purposes of discussion, we will break ATHOS down into component areas: the sampling nacelle; the detection system, including the sampling flow tube, detection axes, and vacuum pumps; the laser system; and the electronics.

Sampling nacelle.

The DC-8 aircraft flies at about 0.8 - 0.85 M. Slowing the airflow from this speed to that required for ATHOS, about 5-40 m s^{-1}, is difficult to do without creating shocks and disturbed flow. Because OH is so reactive, we consider that any collision with the surface will result in OH loss. A solution to this problem has been devised by Kevin James at NASA Ames Research Center. He has designed a sampling nacelle that consists of two concentric nacelles that are shaped as cylindrical airfoils with the concave surfaces on the outside. He has placed the inner nacelle at the point where the air is going slowest inside the outer nacelle and has placed the sampling flow tube inlet at the point where the air inside the inner nacelle is going slowest. A "plug" positioned at the aft of the inner nacelle can be moved in or out to control the air flow velocity inside the inner nacelle. Dr. James has done extensive computer calculations and optimizations of this design and together with colleagues at Iowa State University has performed wind tunnel tests at low airspeeds for verification of the computer codes.

Detection system

Most of the detection system already exists as part of our ground-based instrument. A detailed description can be found in Stevens et al. (1994). In the ground-based system, we detected OH and HO_2 with the same detection axis and so could not measure them both simultaneously. For ATHOS, two detection axes will be used, the first for OH and the second for HO_2. They will be intercompared periodically by turning off the NO reagent flow to the second axis. Detection sensitivities equal to or better than the ground-based instrument are projected to be achieved.

Laser system

The laser system employed for our ground-based instrument has proven to be too difficult to use during deployments and would be very difficult to implement reliably on an aircraft. We have for the last year been pursuing two other laser designs as replacements for the current copper laser pumped dye laser system.

The first system involves a small solid state Nd:YAG laser pumping a copy of the Harvard dye laser that has been used so successfully on the NASA ER-2 aircraft. The original plan was to use two TFR solid state Nd:YLF lasers from Spectra Physics to pump this dye laser. They have a combined power of about 1 W at a repetition rate of 5 kHz. However, tests at Harvard with our dye laser and their TFR lasers showed that this arrangement would not produce enough 308 nm laser power for our needs. Second, because of the design of the dye laser cavity, the "tail" of the laser pulse is quite long. Because we separate Rayleigh and chamber scattering from the OH fluorescence by turning the detector on only after the laser pulse is ended, this long tail to the laser pulse creates a large background signal that cannot be eliminated.

Recent developments in solid state laser technology have resulted in much more powerful solid state Nd:YAG and Nd:YLF lasers. In addition, new crystal materials that transmit in the ultraviolet now are being used as optical shutters. We are pursuing a laser system that uses a single 2 W solid state Nd:YAG laser to pump the dye laser. If we can get enough laser power at 308 nm from this combination, then we will use an optical shutter at the exit of the dye laser to chop off the tail of the laser pulse. However, a demonstration laser to test this arrangement will not be available for another two months. This option, which requires less than 1 kW of power, may not be available for the first version of ATHOS.

The second option is a Ti:sapphire laser that is frequency-tripled into the ultraviolet. This system has demonstrated sufficient laser power at 308 nm and the pulse tail is very short. However, this system has some draw-backs. First, getting the laser to be stable at a narrow linewidth has been difficult. This problem should be solved soon by careful thermal and mechanical design of the optical mounts and by selection of the correct optical elements. Second, the laser system, including water cooling with a chiller, consumes approximately 6 kW. This large power requirement can be solved only by replacing the flashlamps in the Nd:YAG pump laser with solid state diode laser bars. However, this development project could not be completed in time for us to have the instrument ready for early 1996. The flashlamp pumped version is all that is presently available.

Given these two choices, our plan is to adapt the Ti:sapphire laser to aircraft use. A preliminary layout of a compact aircraft version of the laser is complete already. Detailed design will begin once the laser stability and narrow linewidth issues are settled.

Electronics

Most of the data collection and instrument control system exists and most of the software will be developed and tested within a month. The system is based on components designed by T. Thompson of the NOAA Aeronomy Laboratory (Figure 5). An additional board for the fast, gated detectors has been built and will be tested once the laser system is operational. Some sensors to monitor instrument operation need to be identified and integrated into the system, but the core of the electronics system exists and is tested.

Good software control and monitoring of instrument function will be essential for this instrument since it will be located in the forward cargo bay while the operators are in the main cabin. The goal is to have ATHOS operate autonomously within a year after installation in the DC-8.

Summary

ATHOS combines many new and unique components and technologies with proven ones and will be the first instrument to our knowledge to sample trace gases from the underside of the DC-8. It will operate semi-autonomously and be capable of producing real-time, quick-look data. All tests suggest that ATHOS will be capable of OH and HO_2 measurements that meet or exceed the requirements for aircraft missions such as SUCCESS or PEM-Tropics.

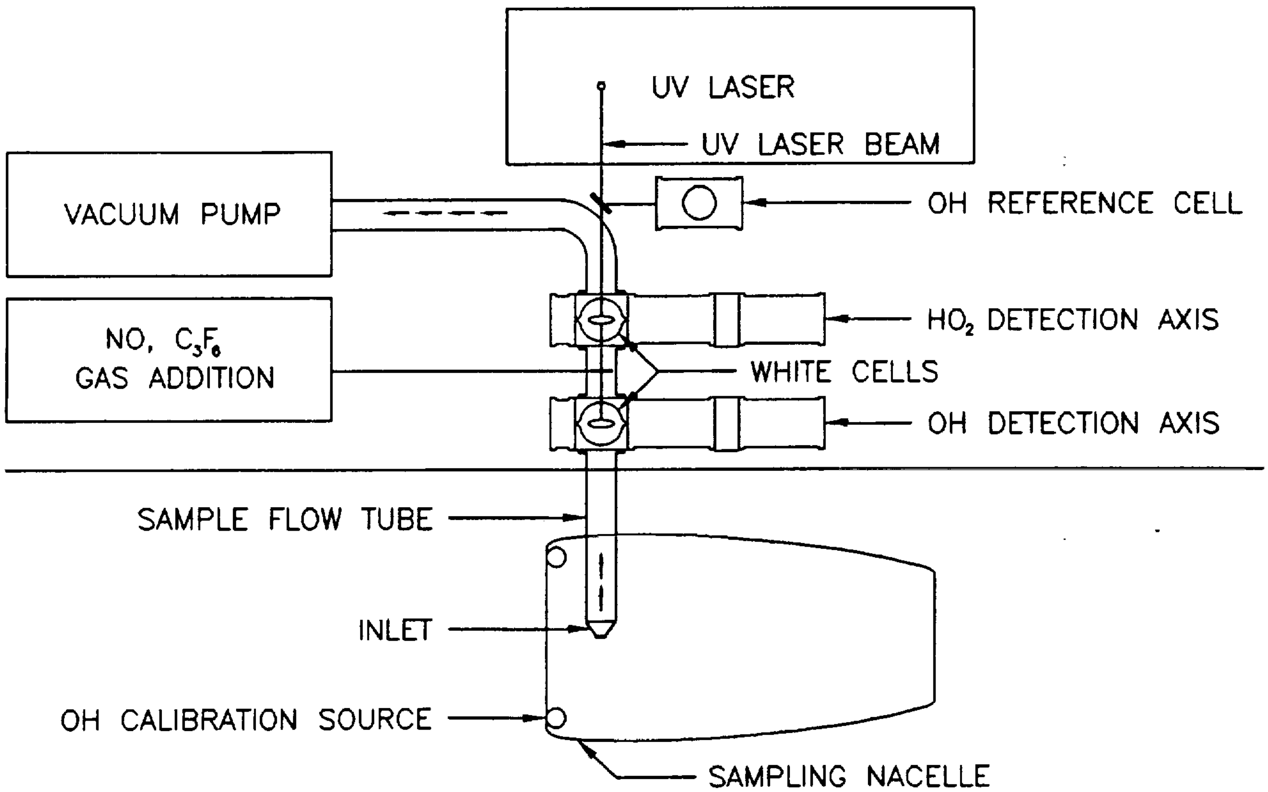

Figure 1. Schematic of ATHOS instrument. The major components are the sampling nacelle, the sample flow tube, the OH and HO_2 detection axes, the vacuum pumps, and the UV laser system. Not shown are the data collection and control and electrical power systems.

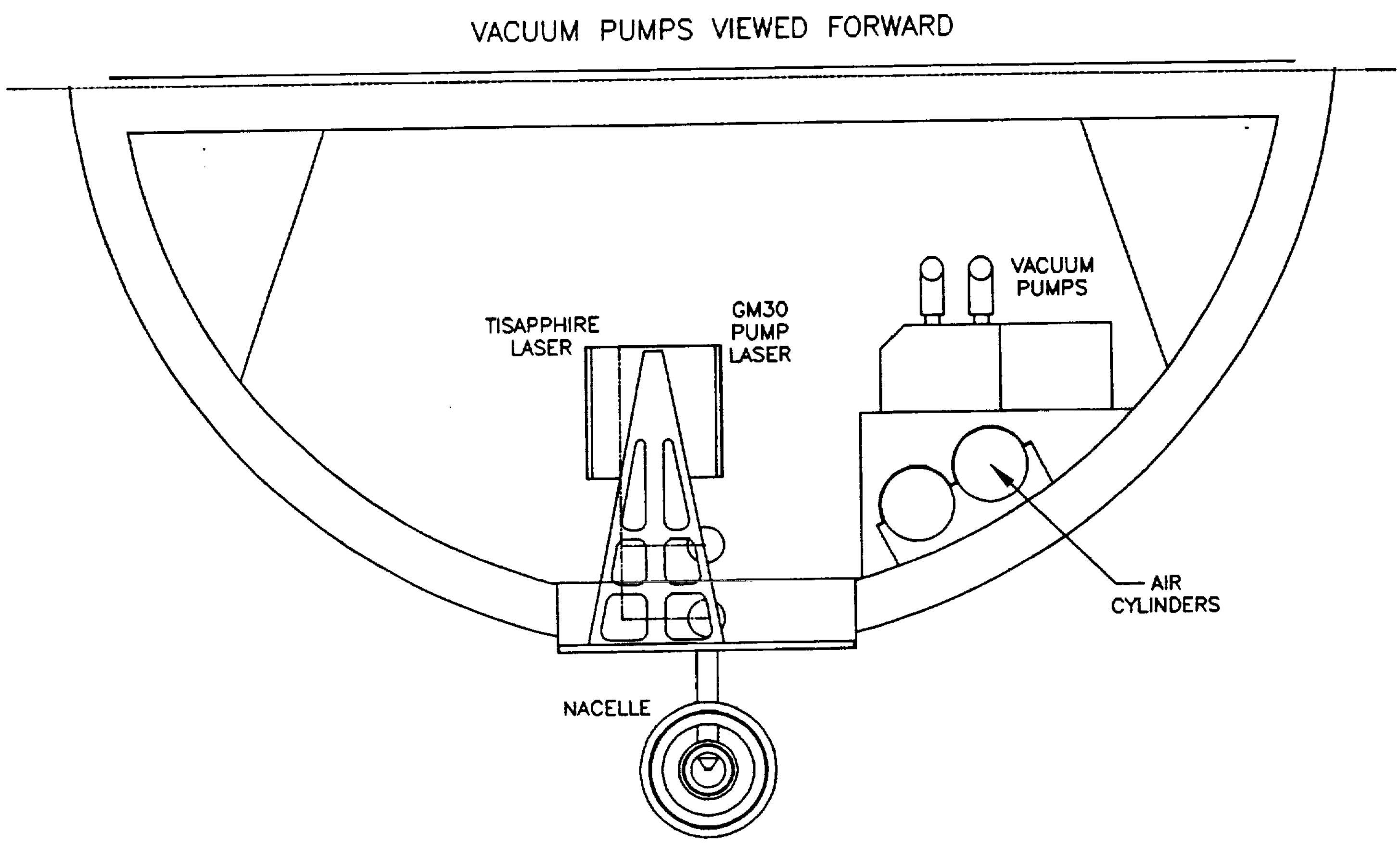

Figure 2. Preliminary drawing of front view of ATHOS in the DC-8 forward cargo bay.

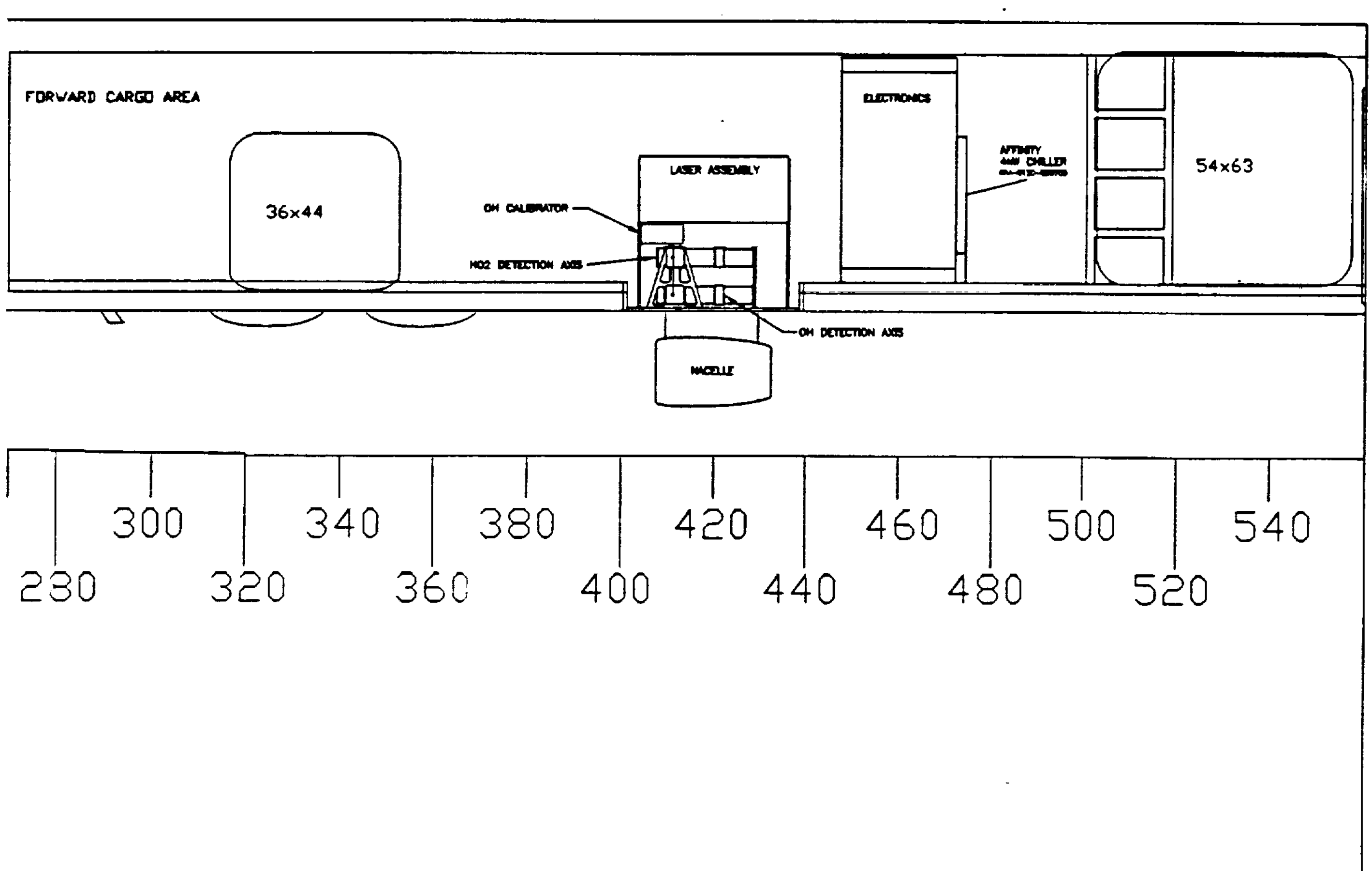

Figure 3. Preliminary drawing of side view of ATHOS in the DC-8 forward cargo bay.

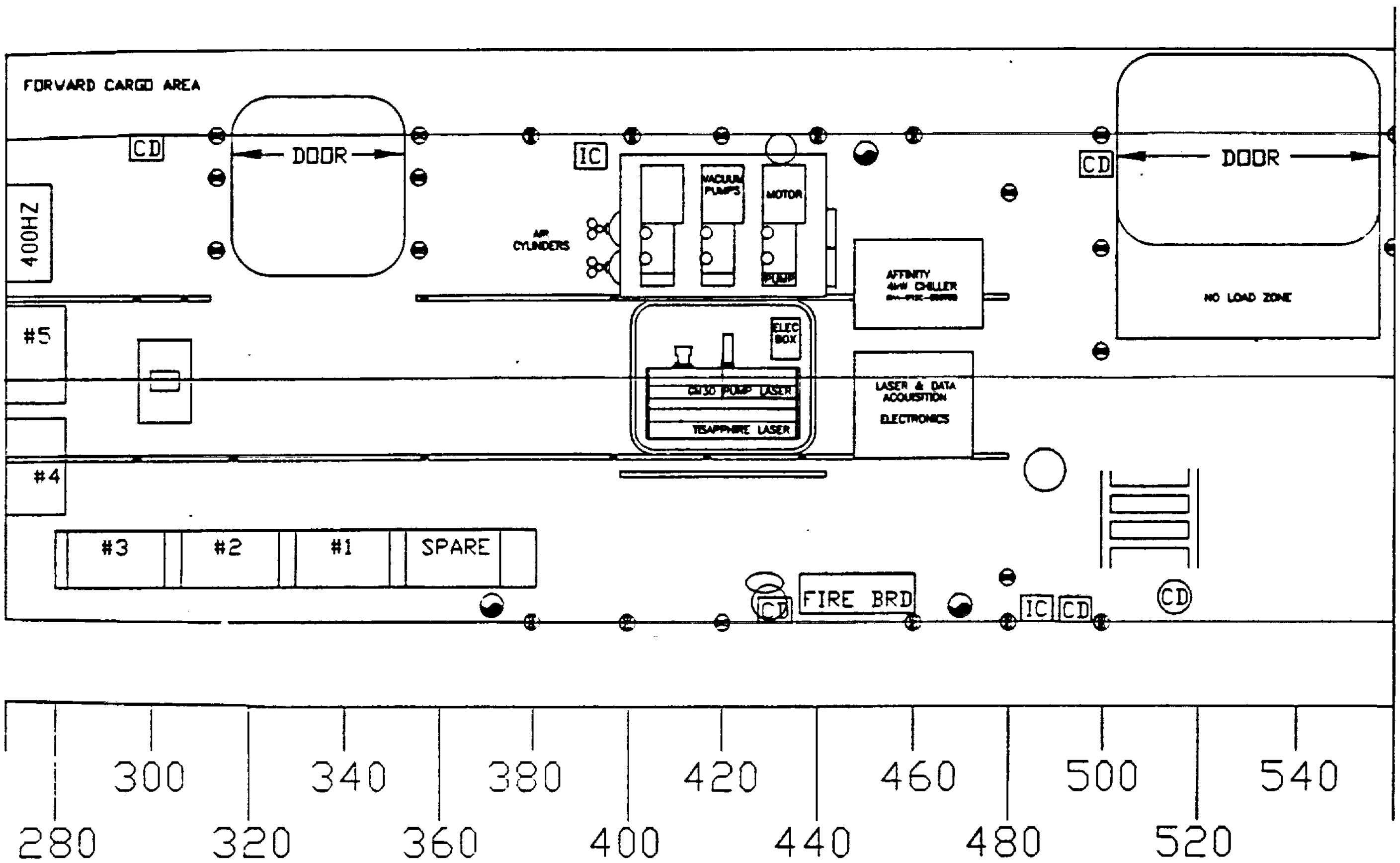

Figure 4. Preliminary drawing of top view of ATHOS in the DC-8 forward cargo bay.

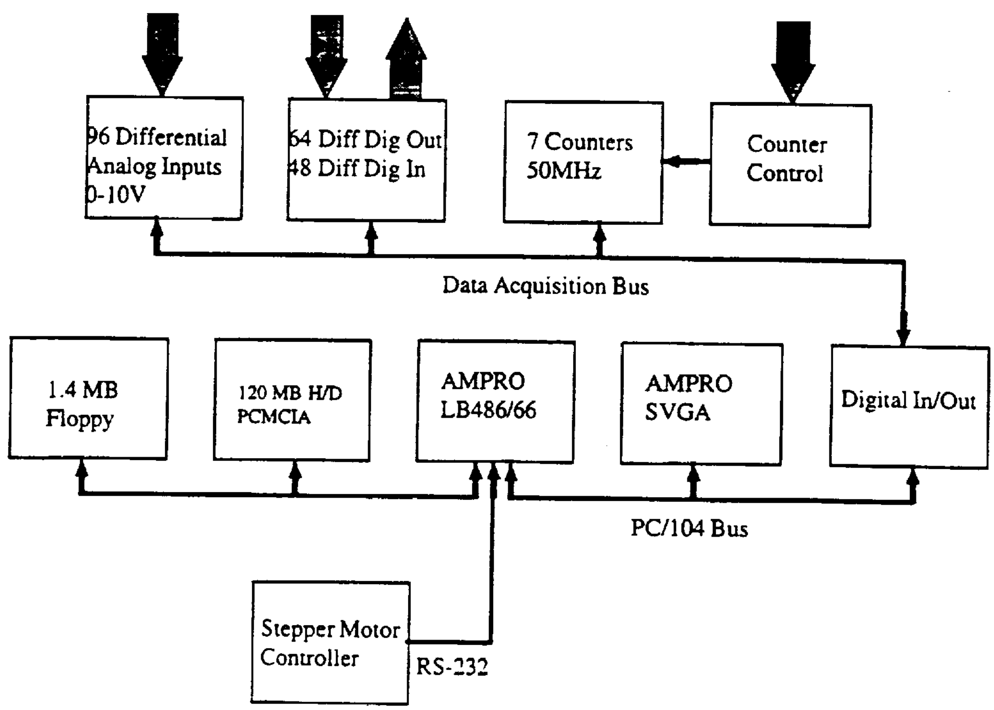

Figure 5. Schematic of the data collection and computer control system for ATHOS. Thick arrows indicate the connections to the sensors and detectors for the instrument.